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Zero Tillage Impacts on Soil Environment and Properties

Rajan Bhatt

University Seed Farm, Usman, Tarn Taran, Punjab Agricultural University, Ludhiana, Punjab, India

Edited by:
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Abstract: Tillage-mechanical manipulation of the soil done to have a fine seed bed, get rid of weeds and to decrease the leaching and percolation losses for the better land productivity but on the long run observed to have negative effects on the soil properties, structure and finally onto the environment. Agriculture contributes to greenhouse gas affecting the atmosphere. Processes of climate change mitigation and adaptation delineate zero tillage (ZT) as environment friendly. But initially ZT performance is still in question because of higher weed biomass. Number of scientists reported differential effects of the ZT on soil health, properties and the environment. However, its adoption still under doubt as farmers doesn't agree to divert from the old indigenous lines. Among tillage viz. conventional (CT), minimum (MT) and ZT-their effects on the soil properties and crop yield varied. Therefore, choice of any tillage system is too critical for maintenance of the soil physical properties necessary for crop growth. However, effect of different tillage systems on soil properties depends on the site-specific biophysical environment such as soil texture, prevailing climate variations, site characteristics, period of adoption, seasonal variability in rainfall, inherent soil fertility status. Till now there is confusion among not only in farmers but also in scientists regarding performance of different tillage systems with respect to soil health, land and water productivity and the environment. Further, their residual effects during intervening period have not been attended much till date. Keeping all this under consideration, this review is compiled to come out with a perfect tillage system which ultimately leads to the sustainable/climate smart agriculture. Finally, we concluded that minimum tillage has an edge from both other tillage system and found to be best in texturally divergent soils under different agro-climatic conditions.

Keywords: Conservation agriculture, environment, mulching, soil, sustainable agriculture ZT,
Corresponding author: Rajan Bhatt: rajansoils@gmail.com, rajansoils@pau.edu

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1 Introduction

Tillage –a must use practice in the rice–wheat cropping sequence (RWCS) led to natural resources deterioration (Hira, 2004; Kukal et al. 2014). Rice is established in puddle soils with heavy water and labor inputs (Dawe, 2005), causes sub-surface compaction because of repeated puddlings (Sur et al., 1981; Kukal and Aggarwal, 2003a) restricts the root growth of wheat in addition to creating aeration stress (Kukal and Aggarwal 2003b). Repeated puddling of coarse and medium textured soils affected its properties by dispersing aggregates into sand, silt and clay which induced changes in structure, bulk density, infiltration rate, pore size distribution, hydraulic conductivity, the cone index and gained strength during the subsidence stage. Thus, the conventional indigenous tillage practices of extensive tillage used to establish rice-wheat cropping sequence has taken a toll on the natural resources (Bhatt, 2015).

To address these challenges of RWCS, resource conservation technologies (RCT) based alternative tillage and crop establishment methods viz. ZTW-DSRZT have been designed and tested in IGP (Malik et al., 2011; Jat et al., 2013). The RCTs involves a paradigm shift from intensive tillage to zero or minimum tillage, establishment of permanent organic soil cover with economically viable crop rotation that complement reduced tillage and residue retention. Soil physical properties improved by the double ZT which further improved the productivity, profitability and sustainability of the RWCS (Bhaduri et al. 2014; Dikgwatlhe et al., 2014). However, the magnitude of benefits of RCTs viz. ZT are both site and situation specific and cannot be generalized across farming systems (Hobbs, 2007). Further, their significant effects only be observed after a set period of time (Bhatt and Kukal, 2015e; Jat et al. 2014).

Generally, ZT adopted only during wheat season but to reap the full potential benefits of ZT, both crops viz. rice and wheat need to be established this technique (Jat et al. 2006b; Bhushan et al. 2007). Further, ZT plots reported to be suffering from the significantly higher weed pressure because of surface placed seeds and better availability of water and nutrients (Singh et al 2015a, b; Bhatt 2015) and because of reported lesser herbicide efficacy here (Singh 2015c). However, few studies present in literature showing the effect of double ZT in the RWCS on the physical environment and still doubts are there as within two years of adoption (Bhatt and Kukal, 2015e) some studies showed the significant improvement (Jat et al, 2009). Research on ZT has often occurred within the context of conservation agriculture (CA). CA represents a set of three principles: minimum soil disturbance (including ZT), crop rotation, and residue retention/permanent soil cover (FAO, 2011).

Direct drilling of wheat seeds in standing rice stubble in untilled soil is an important RCT being propagated in South Asia (Beff et al. 2013; Singh et al. 2014). The influence of ZT systems on crop production (Paccard et al. 2015), water use efficiency (Guan et al. 2015), carbon sequestration (Zhangliu et al. 2015) and economic performance (Tripathi et al., 2013) are well recognized. However, for better irrigation water management it is important to understand soil water dynamics in comparison to conventional system throughout the soil profile. ZT improves the soil physical environment (Paccard et al. 2015; Bhaduri et al. 2014) because of residue retention in the fields resulting in increased infiltration rate, water retention, hydraulic conductivity, lower soil compaction (Zheng et al. 2015; Palese et al., 2014; Bhaduri et al. 2014) etc. while CT break macro-aggregates into the micro-aggregates which adversely affect the soil properties (Das et al. 2014; Kuotsu et al., 2014; Roper et al., 2013). Thus, higher yields are expected in the ZT plots because of better edaphic environment and water retention but contradictory results are reported in the literature (Singh et al. 2015; Chopra and Chopra, 2010). Further, Chang and Lindwall (1990) documented that soil properties modification by differential tillage practices are related to soil texture, tillage equipment, tillage depth, soil physico-chemical conditions and climatic conditions during tillage. Keeping above points under consideration, the present review is compiled from different studies carried out in different parts of the region (with divergent soil textural classes and climate) so as to have a clear opinion about ZT and their effect on the soil properties, land productivity, livelihoods and finally on to the environment.

2. Zero tillage and soil properties:

ZT affects the physical, chemical and biological properties of the soil in an entirely differently pattern to as that of what CT did. No-till in the context of CA can also lead to improvements in soil quality by improving soil structure and enhancing soil bio-logical activity, nutrient cycling, soil water holding capacity, water infiltration and water use efficiency (Hobbs et al. 2008). Under ZT wheat seeds are directly drilled into the standing rice stubbles without much disturbing the soil. Following is the discussion for the detailed effect of the ZT technique on the different soil properties and environment.

2.1 Chemical properties

2.1.1. EC: Non-significant effect of tillage weather It is ZT, rotary tillage, minimum tillage or CT observed after the carried out two years of the experiments in both loam sand as well as sandy loam soil (Singh and Singh, 2014). Further Ghulam et al. 2014 reported that ZT with highest EC value and CT with lowest EC values. The results of the study had been inconsistent with Chatterjee and Lal (2009). They delineated that lower electrical conductivity of soil under the ZT system compared with CT pertains to the enhanced water movement in the soil and improved soil aggregate development.

2.1.2. Soil pH

Long term adoption of the ZT resulting in acidification of the surface soil which further affects the supply and distribution of other nutrients within the rhizosphere. Under ZT, a significant lowering of pH observed at the upper soil 0-7.5 cm on silt loam soil (Dick et al. 1986). In Kentucky, soil acidity with ZT observed due to decomposition of organic residues at the surface with subsequent leaching of resultant organic acids into mineral soil (Blevins et al. 1977; Mutschler et al. 1973) while contradictory results reported by Calegari 1995 in their long-term experiments in Brazil. Running over the same track, Kaminski et al. (2000) reported higher pH under undisturbed ZT than that of under ploughed soils and they claimed reported higher organic matter a reason for that. Thus, ZT in general resulted in the acidification of the surface soil.

2.1.3. Distribution of nutrients

ZT reported to accumulate higher nutrients closer to surface as zero tilled 16 years old wheat experimental plots hoarded greater No3 -N, SO_4- S, and PO_4 –P in upper 2.5 cm than tilled plots (Tracy et al. 1990). Mineralization of organic nutrients viz. sulfur, nitrogen and phosphorus might be a major source of available nutrients near the ZT soil surface. At 0-5 cm, greater exchangeable potassium reported in ZT experimental plots. Mechanical mixing of soil as in CT was mainly responsible for the potash accumulation in the deeper soil layers depending on plowing depth (Blevins and Frye, 1993). CT systems mineralized more nitrogen at the soil surface due to soil disturbance (Halvorson et al. 2001; Malhi et al. 2006). CT recorded significantly higher values of soil phosphorus and potash than that of the ZT (Gangwar et al. 2004; Singh 2006). As per Dinnes et al. (2002) during the tillage process and incorporation of surface residue increased the soil aeration and rate of residue decomposition which further affected the soil organic nitrogen mineralization. According to Gangwar et al. (2004) during initial phase of the tillage experiments, soil available phosphorus and potash not affected after each crop sequence (Bhatt and Kukal, 2015e). Higher organic carbon status was reported under zero tilled plots compared than that of the conventional tilled plots. Thus, under ZT, nutrient availability increased near the soil surface which might be available to the seeds weather it is of economical crop or of the weeds (Bhatt, 2015).

2.1.3 Organic matter of Soil:

Both quality and quantity of the organic matter (OM) in a particular soil is indicators of its quality as it affects almost all the physico-chemical properties. Generally, OM content of upper vadose zone of the soil under ZT is higher, than for tilled soil. The OM quantity will generally improve with conservation tillage, but remain fairly constant, or perhaps decrease further, with intensive tillage (Frye et al., 1985). Increase in soil OM in coarser particles reported up to 0.2 m soil depth under ZT after 4 years (Freitas et al., 1999), while Riezebos and Loerts, 1998 quoted a decrease in OM compared to tilled soil down to a depth of 0.1 m after 3 years in a oxisol. Further, no significant improvement in OM status was observed even after 13 years of ZT in a clayey Typic Hapludox oxisol (Sisti et al., 2004) while Six et al. (2002) observed improvement in soil OM status in the upper 0.4 m of even after 6-8 years of ZT. Thus, ZT performance is affected by many factors.

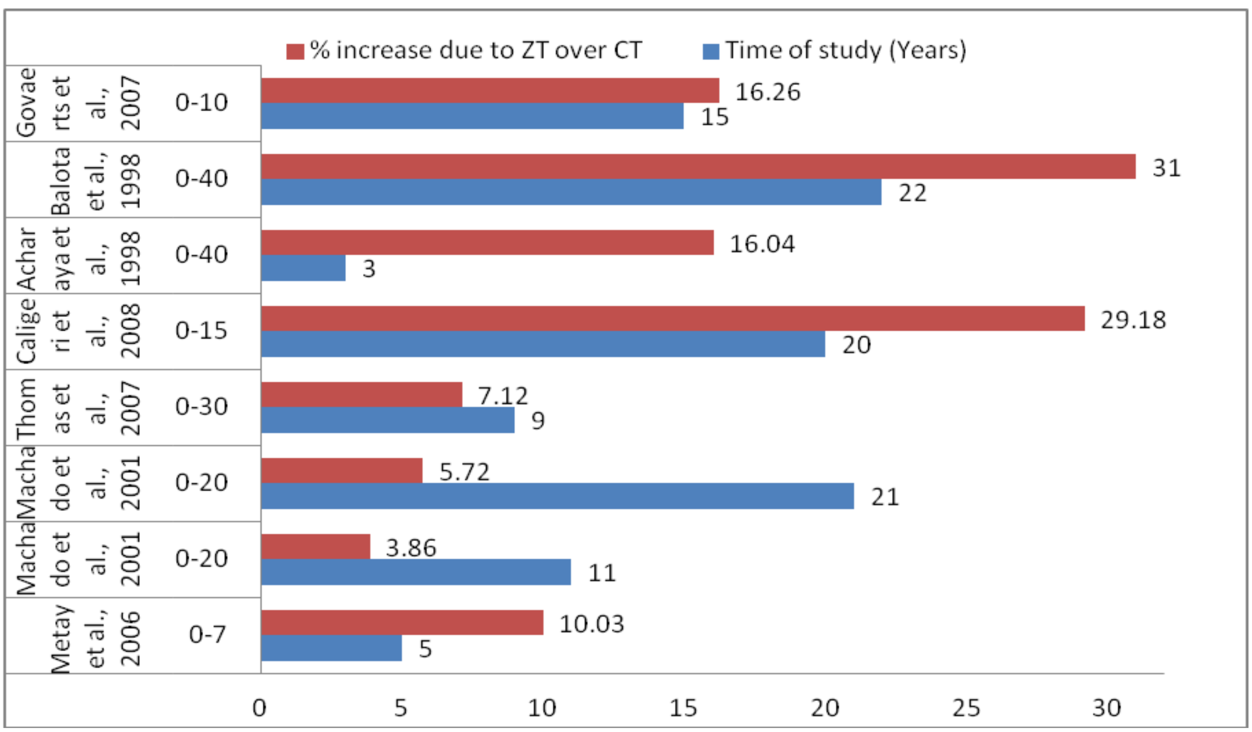

Fig. 1: Percent increase in soil organic carbon due to adoption of ZT (Adapted from Jat et al. 2012).

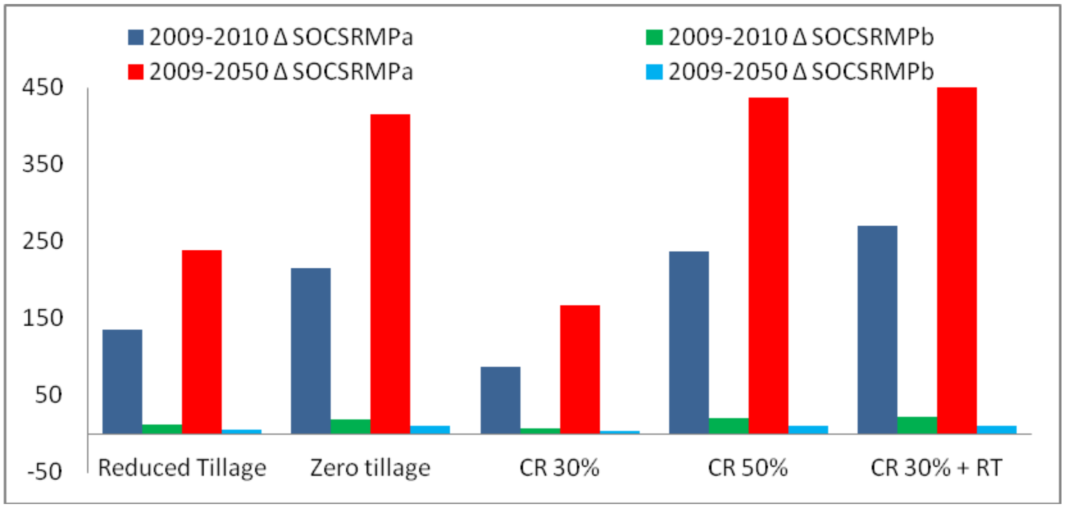

Fig. 2 Carbon sequestration potential (0-30 cm) in (1980-2050) under recommended management practices (RMPs) using DNDC model a=C sequestration potential (Tg C), b= Average rate of C-sequestration (Tg C yr^{-1}) Chinese paddy soil (Adapted from Xu et al. 2011)

Mielniczuk (2003) observed 5-6% higher rate of mineralization of soil OM per year under conservation tillage regimes compared to zero tilled conditions where it was 3% per year. Bornoux et al. (2006) reported higher carbon accumulation rates (around 0.4 – 1.7 t C ha^{-1} year $^{-1}$) under zero tilled conditions compared to tilled condition. Subbulakshmi (2007) stressed that, soil organic matter status was not significantly improved by tillage methods under clay loam soils. Further, Jat et al (2012) reported that longer the duration of adoption of ZT higher is the buildup of the soil OM (Fig. 1). At Chinese paddy soil under zero till conditions Xu et al, 2010 using DNDC model reported that after 70 years highest build up of the soil organic carbon than that of the other options (Fig. 2). Thus, ZT reported to increase the organic matter status of the soil but a set period is required otherwise OM status seems to be non-significantly improved than that of the conventionally tilled soil.

2.2 Soil Biological properties

ZT conditions were observed to be better for both micro and macro soil organisms. Greater number of worm channels and to their continuity, which was better in no-tilled soil than in plowed soil attributed the higher infiltration rate of loess soil in Germany (Ehlers 1979). Hopp and Slater, 1961 reported that earthworm channels, which increase soil porosity, are highly stable and provide for rapid water entry into a soil. In comparison to that of conventional tilled plots, Lal, 1976 reported greater earthworm activity (up to five times) in ZT plots. Doran (1980) reported 35 and 57 per cent higher aerobic counts and facultative anaerobic counts under ZT conditions. The population of denitrifying bacteria was almost half in tilled plots in compared to than that of the ZT plots while Stately and Fairchild (1978) reported non-significant effects of tillage on the denitrifier population size. Burford et al. (1977) reported three to five times higher N_2O flux under zero tilled plots. Crops grown on zero tilled plots recorded more insect activity than tilled plots (Kaminski et al., 2000). Thus, ZT improved the soil biological properties by creating more favorable environment for their better proliferation in the soil.

2.2.1. Potentially mineralizable N: Contradictory reports regarding tillage effects on the potentially mineralizable N by the scientists across the globe available in literature. Kheyrodin and Antoun (2009) observed that tillage significantly increased the soil N mineralization rate. The potentially mineralizable nitrogen (N_0) was higher in CT than in ZT plots and was maximum at upper 6” soil as mineralizable carbon (Cm) and nitrogen (Nm) significantly decreased in 15 – 30 cm depth. El-Haris et al. (1983) documented nitrogen mineralization was unaffected by tillage practices in the 6” depth during rainfalls where during spring season, rate was significantly higher in the chisel ploughed plots. Bennett et al. (1975) delineated that Nm in the surface 6” layer was higher for the ZT than for CT corn (*Zea mays* L.) plots. Carter and Rennie (1982) reported that potential net mineralizable C and N were significantly greater in surface soil under ZT in comparison to CT. Thus mineralization rate as per studies decreased with soil manipulation with tillage.

2.2.2. Soil respiration: CO_2 flux as impacted by agricultural management practice need to be delineated (Reicosky, 1997). Tillage opens the soil, thus improves the soil respiration and increased the emission of the CO_2 (Reicosky and Archer, 2007). Nowadays, a rapid increase of CO_2 in environment is one of the main issues because of reported global warming consequences (Wood, 1990). However, soil management practices need to be refined to reduce soil respiration and organic matter decomposition without decreasing crop yield, ZT might be suitable answer. But scientists are of different opinions as some reported similar soil CO_2 emission rates from ZT and CT (Elder and Lal, 2008), while Oorts et al. (2007) observed large CO_2 emissions under zero-tillage in comparison to the CT. Thus, a bridge between the two tillage systems might be an answer.

2.2.3. Soil microbial C and N: Tillage operations interrupts soil aggregates exposing organic matter to microbial degradation which finally oxidizes OM to CO_2. Balota et al. (2004) reported that ZT significantly increased the soil microbial biomass C (MBC) as compared to the CT. Bhatt and Kukal (2015) in their two-year study on the sandy loam soil reported non-significant effect of the double zero till on soil properties. Further ZT systems improved total C by 45%, microbial biomass by 83% and MBC: total C ratio by 23% at upper 5 cm depth over CT. C and N mineralization enhanced to 74% with ZT upto 0–20 cm depth. Under ZT, the metabolic quotient (CO_2 evolved per unit of MBC) diminished by 32% averaged across soil depths. Thus, tillage produced a microbial pool that was more metabolically active than under ZT systems which further oxidizes the inherent soil-C to CO_2. Currently, sequestration of C in soils is desirable as a mean to mitigate global warming consequences (Burras et al. 2001). Microbial biomass measurements used as an indicator of potential C sequestration (Sa et al., 2001). In this regard, microbial biomass can be a valuable tool for understanding changes in soil properties and in the degree of soil degradation (Sparling, 1997). In long-term ZT plots accumulated higher soil carbon and nitrogen, viable microbial biomass, and phosphatase activities in upper 0–5 cm depth than the CT treatment (Mathew et al., 2011). Soil microbial community structure assessed using phospholipid fatty acid (PLFA) analysis and automated ribosomal intergenic spacer analysis (ARISA) varied by tillage practice and soil depth. The abundance of PLFAs indicative of fungi, bacteria, arbuscular mycorrhizal fungi, and actinobacteria was consistently higher in the ZT surface soil. Thus, CT adversely affected the soil microbial population and ZT favors their proliferation.

2.3 Soil Physical Properties

Soil physical properties changed with the intensive tillage practice but for having significant effect, tillage practice required a set period of time (Bhatt and Kukal, 2015). One feature that is almost always changes by soil tillage is the bulk density (Cassel, 1982). Most changes in the physical environment are adjusted by soil bulk density. Magnitude and direction of changes in bulk density depends on previous soil properties, type and intensity of tillage and time passed from the tillage operation. CT using a moldboard plow, turn a hunk of deep soil to the surface and leads to the creation of large pores in the plow layer which can lead to loss of soil bulk density (Mousavibougar et a1, 2012). Adopted soil manipulation practice and the amount of previous crop residues left on the soil surface, play an important role in maintaining the soil moisture and crop production in arid and semi-arid areas (Hammel, 1995). Infiltration and water movement in the soil can be affected by soil porosity and bulk density (Unger, 1978). Later workers stated that moldboard plowing and other tillage systems, most of which relocating soil particles, increase water infiltration into the soil in the short term, but after a few turns of rainfall soil surface crusting interrupts water infiltration into the soil.

2.3.1. Bulk density

Tillage practices significantly affected the bulk density of the field. ZT reported to increase the bulk density to the highest level (1.69 Mg m^{-3}) while residue incorporation lowered it (1.59 Mg m^{-3}) (Gangwar et al. 2010). In Minnesota, higher bulk densities (1.24 to 1.32 g cm^{-3}) of a clay loam soil reported under ZT than in CT (1.05 to 1.12 g cm^{-3}) (Gantzer and Blake, 1978). In contrast, Blevins and Frye (1993) reported no significant effect of the practiced tillage methods on soil bulk density even after 20 years however at 0-0.5 m soil depths, ZT reported to lower the bulk density.

Journal of Environmental & Agricultural Sciences (JEAS). Volume 10

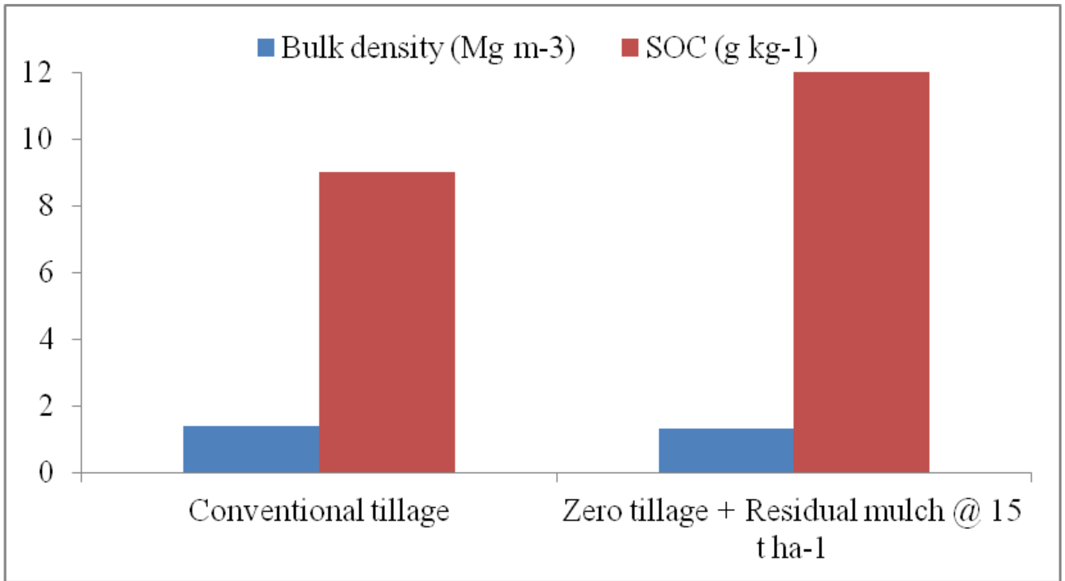

Fig. 3 Soil organic carbon (g kg^{-1}) and bulk density (Mg m^{-3}), of sandy loam soil, at maize harvest under different tillage and crop residue treatments (Adapted from Sharma and Acharya, 2000).

Controversially, it had also been reported that ZT increased bulk density (Lampurlanes and Cantero-Martınez, 2003), lower soil temperatures (Drury et al., 1999), increases the bulk density (Braim et al. 1992) and decreased oxygen diffusion (Russell, 1988). Considering this fact, Lampurlanes et al. 2001 argued that as ZT compacted upper soil layers and therefore this technology might be less appropriate during wet years. Braim et al. (1992) and Kirkegaard et al. (1995) also reported reduces the wheat growth under zero tilled conditions because of increased bulk density. Hill and Cruse (1985) under loess-derived Iowa soil reported non-significant effect of tillage methods viz. zero, conventional and minimum tillage on bulk density. Rice yield reduction in ZT was observed mainly due to higher bulk density of surface soil layer (Sharma et al., 1988) while CT practices resulted in lower bulk density (Pratibha et al., 1994; Cavalaris and Gemtos, 2002) due to churning of the soil and break down of the aggregates (John Anurag and Singh, 2007). Further, ZT practices on long run increased bulk density and compaction by decreasing porosity (Munkholm et al., 2001; Strudley et al., 2008). Contradictorily, Jat et al. (2009) reported that the tilled system in 10–15 and 15–20 cm soil layers had higher bulk density and penetration resistance due to compaction caused by the repeated wet tillage in rice while Bhatt and Kukal (2015e) under sandy-loam soil after two years of investigation reported that tillage systems had non-significant effect on the bulk density of the soil profile indicating that resource conservation technologies requires around 5-8 years to have their significant effects on to the soil physical properties. Further Sharma and Acharya, (2000) came out with a conclusion that zero tilled mulched plots under sandy-loam soil reported to have significant reduction in the bulk density and significant hike in soil organic carbon than that of CT (Fig. 3). Thus, ZT increased the bulk density at the surface soil but ZT + mulching will decrease the bulk density. Thus, ZT along with mulching is an answer for mitigating the adverse effects of the ZT.

2.3.2. Soil aggregation

Soil aggregation is an important physical property and is affected by divergent tillage methods. According to Mannering et al. (1975) and Edwards et al. (1988), soil aggregation decreased in CT plots as tillage break down the aggregates. Aggregation was highest in the 0-0.05 m layer of ZT plots. Long term adoption of the ZT will certainly improve the aggregate stability of the topsoil (Douglas and Goss, 1982). Lal et al. (1989) reported that aggregate size tended to be around 22% higher under ZT treatments in comparison to that of tilled plots. Borges et al. (1997) observed that ZT restored water aggregate stability up to 70% of original levels of untilled soil.

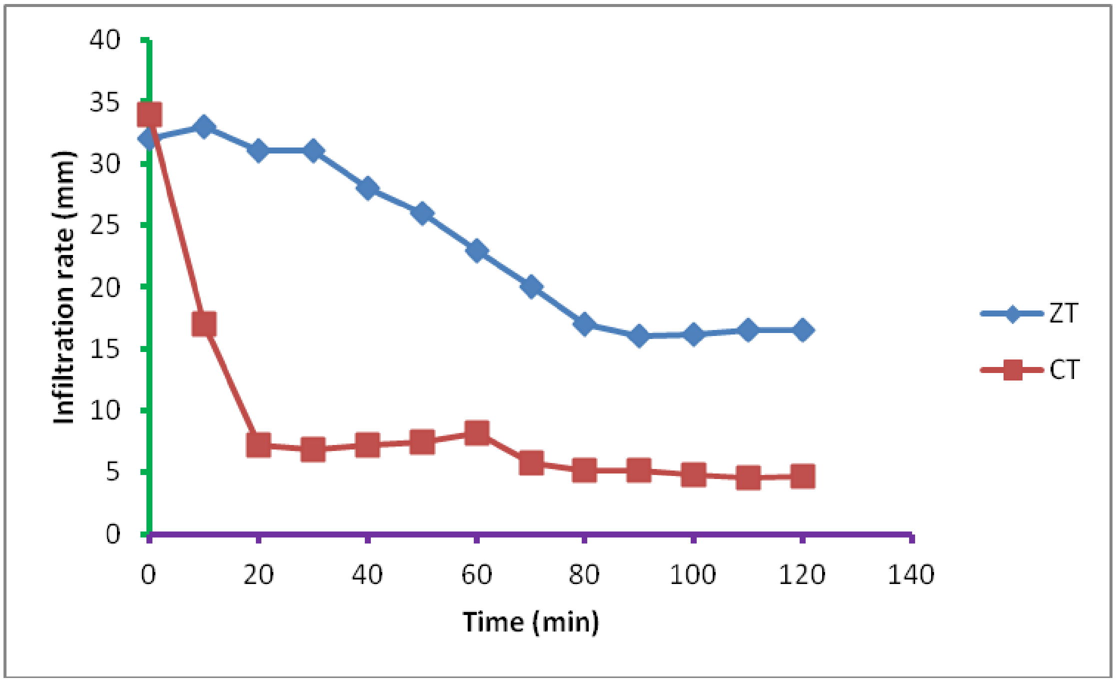

Fig. 4. Change in soil infiltration rate (within 120 minutes) of silt clay loam soil, after 16-year of no-till and conventional till experiment (Silt Clay Loam (Adapted from Sin et al., 2009).

Soil under ZT have better aggregates, aggregate stability, increased porosity which further improved rhizosphere environment for the better plant growth while intensive tillage led to decline in soil organic matter through accelerated oxidation of the organic matter (Ghuman and Sur, 2001; Francis and Knight, 1993; Martino and Shaykewich, 1994; Ghosh et al., 2010). ZT improved macro-aggregation (>0.25 mm) and mean weight diameter which further improved carbon sequestration potential of these soils (Franzluebbers and Arshad, 1996; McConkey et al., 2003). Thus, most studies coined that aggregation improved with the adoption of the ZT but again to have its significant effect, ZT must be adopted for about 5-8 years (Bhatt, 2015; Bhatt and Kukal, 2015e).

2.3.3. Infiltration

Infiltration is the basic properties of soil controlling plant growth. It was already reported that divergent tillage methods affect the infiltration rates as Ehlers (1979) on silty soils reported that ZT increased concentrations of organic matter which further improved the soil structure, and finally infiltration near the surface. As per Mc Garry et al (2000) and Scopel and Findeling (2001) reported that infiltration improved due to more pores, pores being continuous and vertical under ZT and it further improved with increasing amounts of residue on these plots (Lang and Mallett 1984). Surface residues or mulches, as under conservation tillage systems, reduce runoff (1.2 and 2.2 %) and increase infiltration than conventionally tilled soil (8.3 and 21.5 %) at 1 and 15% slope respectively (Rockwood and Lal, 1974).

2.3.4 Soil water storage

According to Gangwar et al. 2010, minimum infiltration rates observed in the zero tilled plots (0.75 cm h-1) followed by plots where residue burned (1.44 cm h^{-1}) and highest in plots where residues incorporated (1.50 cm h^{-1}). Lindstrom et al. (1984) stated that, no tilled plots characterized by higher bulk density, greater penetrometer resistance, lesser macropores and reduced infiltration rate. Subbulakshmi (2007) observed soil crusting on zero-till plots at a slower rate. Arshad et al. (1999) coined higher water retention and infiltration rates under zero tilled plots which might be due to the redistribution of pore size classes into more small pores (Table 1). Further Zin et al, 2009 also concludes the same results on comparing 16 years of zero tilled plots with conventionally tilled ones (Fig. 4). Thus, infiltration rate improved after long term adoption of ZT. Soil matric potential (SMP) is the main driving force which causes the soil moisture to move from one point to other depending on its energy state (Bhatt et al., 2014b) and SMP is effected by divergent tillage methods (Bhatt, 2015). ZT wheat mulched plots dried at a slower pace than that of the CT unmulched plots of wheat (Bhatt, 2015; Drury et al., 1999).

Table 1. Infiltration rate as affected by different tillage and crop residue management system (Soil type Silt Loam) (Source: Arshad et al. 1999)

Cumulative time (min)	Infiltration rate (cm h^{-1})	
	Conventional Tillage	Zero Tillage
10	25	25
20	12.5	12.5
25	6.5	9.7
33	4.5	6.8
78	4.6	6.5
120	4.5	6.3
150	4.4	6.2
185	4.2	6.2

Further, Unger, 1984 in an irrigated experiment testified maximum soil water content during intervening period after wheat under ZT plots than under CT plots. Conservation tillage helps in conserving higher moisture contents than that of the CT (Ghosh et al., 2010). Carefoot et al. (1990) observed higher soil moisture storage with zero-tillage than with CT which further increases the grain yield of wheat and barley. Contrary to earlier studies, Cannel & Hawes 1994; Lafond et al. 2006; Strudley et al. 2008 reported higher fraction of conserved soil moisture during spring season in the intensively tilled soils. Further, Lampurlanes et al (2001) reported that physical changes that occur in ZT plots, can negatively affect the growth of the main root axes, which limited the uptake of the soil moisture. However, Singh et al. 2015b claimed significantly higher weeds pressure in ZT plots in sandy loam soil responsible for poor performance as weeds compete with the economic plants for moisture and nutrients. Soil tillage intensity had no significant influence on moisture content in a deeper (0.1-0.2 m) layer (Romaneckas et al., 2009). Thus, ZT plots conserved higher amount of soil moisture under mulched conditions.

2.3.5 Evaporation

Water to evaporate, energy to cause phase change and wind to create sufficient vapour pressure difference are the basic needs for the evaporation to occur. Under zero tilled mulched plots, the straw mulch load present over the bare soil surface lowered the rate of evaporation relative to un-mulched conventional tilled plots (Bhatt and Khera, 2006; Bhatt and Kukal, 2014a, Bhatt and Kukal, 2017). Bhatt and Khera (2006) reported that greater the surface cover provided by a particular mode of mulch, greater the moisture conserved by that mode as mulch load cut off the direct contact between the hot sunrays and the bare soil.

Minimum tillage was more effective in conserving soil moisture than CT. Compared with unmulched plots, fully mulched plots had 3 to 7% higher soil moisture content in the 0-30 cm soil depth under minimum tillage plots. Minimum soil temperature of the surface layer was 1.4 to 2.4 ^{O}C lower under fully mulched plots than under un-mulched plots (Bhatt and Khera, 2006) (Fig. 4).

Mulch reduced maximum soil temperature, acts as a barrier between hot sunrays and bare soil, decrease the vapour pressure gradient and thus finally cut off the evaporation losses. As per Donovan and McAndre (2000) ZT mulched plots can be more effective in reducing the evaporation losses and enhancing crop yield more particularly during years of relatively low precipitation in water stressed conditions.

The protection against drought due to mulching lasts 7 to 14 days (Bond and Willis 1969). Smika (1976) while comparing the effects of conventional, minimum and ZT on evaporation losses reported that, among all the tillage modes, the zero tilled mulched plots reported to be evaporated at a lowest pace which further conserve higher fraction of the soil moisture. Zero tilled mulch plots were superior to conventionally tilled un-mulched plots (Utomo, 1986) in suppressing the evaporation losses. Further, Singh et al, 2011 reported higher drying of conventionally tilled soils than that of the zero tilled mulched plots (Fig. 5).

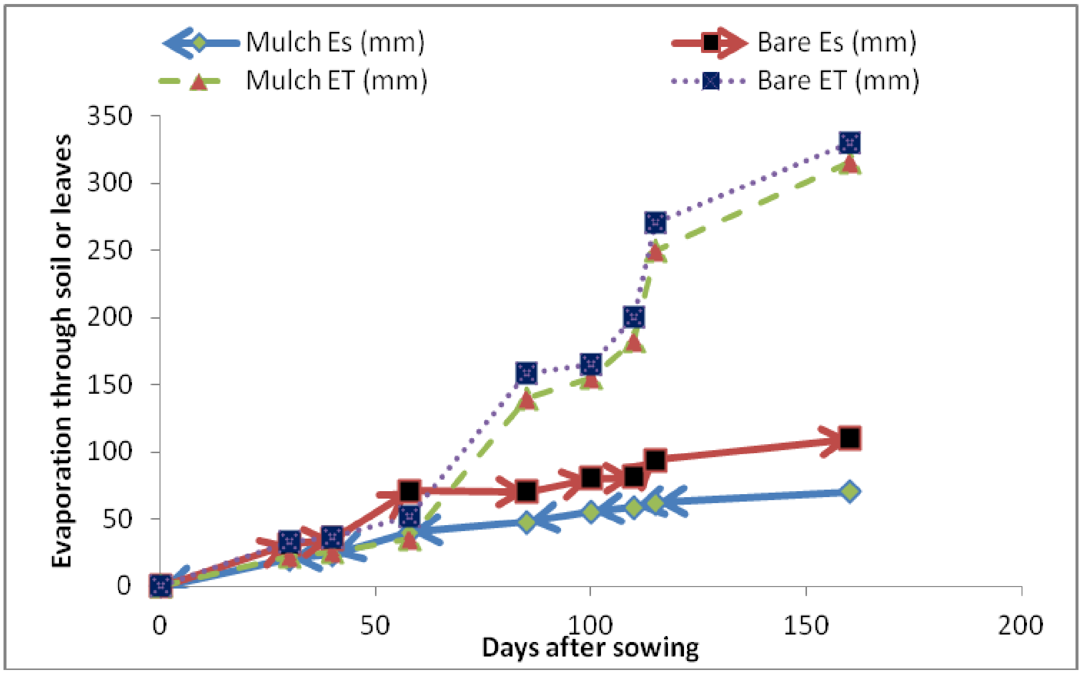

Fig.5. Cumulative evapo-transpiration (ET) and evaporation (Es) of clay loam soil under mulched and non-mulched wheat (Adapted from Singh et al., 2011).

2.3.6. Puddling effects:

Generally, in South Asia rice is transplanted in the puddled soil. Puddling (Process of working saturated or near-saturated soil into soft structure-less mud) deteriorated soil physical properties by breaking down soil aggregates, forming hardpans at shallow depth that leaded to induced changes in pore size distribution; the cone index decreased after puddling and gained strength during the subsidence stage of the puddle soil, and the bulk density of soil increased and hydraulic conductivity decreased 30 and 60 days after puddling Moreover, repeated puddling of coarse and medium textured soils has led to the sub-surface compaction in these soils (Sur et al. 1981; Kukal and Aggarwal 2003a) which has been proving unfavorable for the upland crops like wheat (Kukal and Aggarwal 2003b). The high bulk density layer at 15-20 cm depth formed due to repeated puddling restricts the root growth of upland crops like wheat in addition to creating aeration stress (Aggarwal et al 1995, Kukal and Aggarwal 2003b). Thus, puddle transplanted system of rice is water, capital and energy intensive and leads to structural deterioration of the soil. Thus, there is a need to shift from puddled transplanted system to ZT but some drawbacks are also there. One of them is the significantly developed higher weed pressure. Research on proper herbicides along with proper methodological approach really worked well for proper adoption of ZT in South Asia (Bhatt and Kukal, 2015)

3. Zero tillage and the intervening period:

Till date, even at global level intervening period is least attended as scientists are analyzing the effect of applied treatment on the main crop during the intervening period (Bhatt, 2015; Bhatt and Kukal., 2017). However, most studies carried out in isolation for a single crop without studying the effect of RCT on the succeeding or the proceeding crops in the RWCS. During intervening period, ZT wheat plots evaporates 7.6 % and 12.8 % more, retained 10.3 % and 9.4% lower volumetric moisture content at 7.5 cm soil depths and reported to had 28, 18 and 18% and 21, 16 and 17% higher soil tension values at 10, 20 and 30 cm soil depths because of reported 2.2 % and 2.1 % higher soil temperature than the CT wheat plots after wheat 2012-13 and wheat 2013-14 (Bhatt and Kukal 2015a,b). However, after rice 2013, ZT plots reported to conserve 4.0% higher moisture content because of reported 2.3% lesser soil temperature which evaporates 27.6 % lesser after rice 2013 (Bhatt and Kukal, 2015c). On an average, CTWDSRCT plots had 14, 29 and 45% lower SWT values than the ZTWDSRZT plots after rice 2013. However, after rice 2014, CTW-DSRZT (conventionally tilled wheat and zero till direct seeded rice) plots conserved more moisture than ZTW-DSRZT (zero till wheat and zero till direct seeded rice) plots an exception of CTWDSRCT plots which were almost equally effective in conserving the soil moisture.

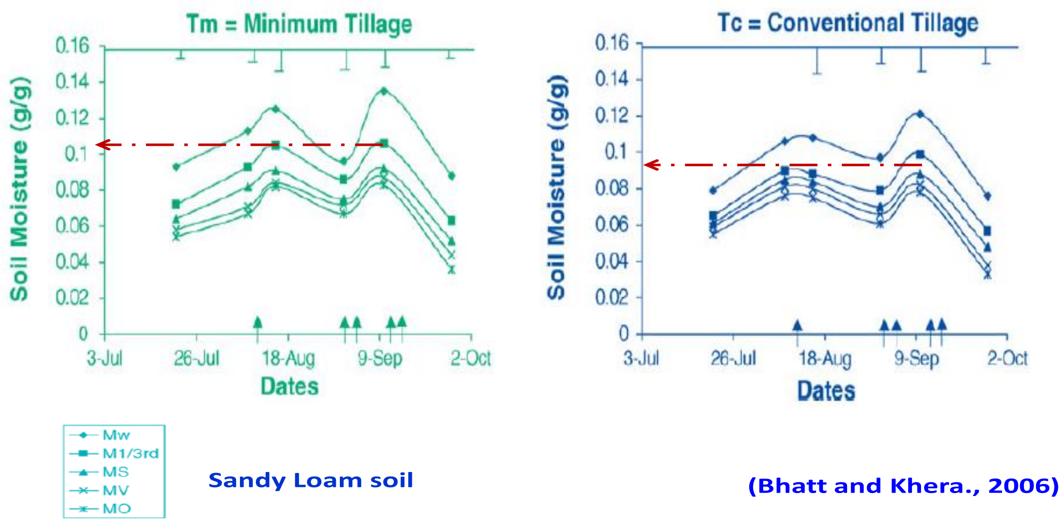

Fig 6. Soil moisture content of surface soil as affected by tillage and different modes of mulch application. (Adapted from Bhatt and Khera, 2006).

On an average, soil matric tension (SMT) reported to be 36% higher in CTWDSRZT than CTWDSRP plots at 10cm soil surface. Further, ZTW-DSRZT plots on an average dried 8% faster than ZTW-DSRP plots. At 20cm, DSRZT plots dried 3% faster than its allied plots while at 30cm depth, in DSRP plots, SMT values increased 12% and 11% higher under CTW block and ZTW blocks, respectively than its allied plots. SMT readings in all the ZTW plots on an average increased at much more faster rates (24%) than CTW plots. The ZT plots had 1.4% higher water depths than the CT plots. Evaporation losses pragmatic to be much higher (17.2% and 7.3%) in ZTW-DSRZT plots as compared to the ZTW-DSRCT and CTW-DSRCT plots which might improved declining crop and water productivity in the region (Bhatt and Kukal 2015c,d).

4. Zero tillage and the antecedent soil moisture:

ZT affected the antecedent soil moisture which is of use during intervening periods (Bhatt and Kukal, 2014). Experiments showing significant moisture variation trends in relation to tillage are usually site and situation specific, and not repeatable in texturally divergent soils. Blevins et al. (1971) reported that upto 0.60 m soil depth; ZT mulched plots had higher volumetric soil antecedent moisture while Bhatt (2015) reported higher volumetric soil moisture content throughout the soil profile starting from the soil surface up to 120 cm than that under conventionally tilled un-mulched conditions

However, Blevins et al. (1971) and Geiszler et al. (1971) differential water withdrawal patterns under differently adopted tillage practices. Tillage methods significantly affected the spring antecedent soil moisture content (Maule 1990). Rydberg (1990) concluded that ZT + M plots reduced the rate of evaporation, mainly by cutting off direct hitting of hot sunrays onto the bare soil, reducing slaking of the surface which was observed because of higher content of un-degraded cop residues and better stability of soil particles. Further, Rydberg (1990) came out with a conclusion that ZT reduced evaporation losses more on a silty clay loam soil than on heavy clay soil, indicating texturally divergent soils behaved in different way. But even then mulching practice did its role. Further, tillage methods influence the amount of moisture in the soil as it affecting the pore space and their distribution. (Burwell et al. (1966). Ojeniyi and Dexter (1979a) and Russell (1961) indicated that different tillage options affects the antecedent soil moisture in a different pattern. Even if the effects of tillage and soil conservation were completely understood, other factors such as rainfall patterns, crop rotation, soil textural class etc. must be considered. Bhatt and Khera, 2006 reported higher moisture regimes under minimum tillage and fully mulched conditions (Fig. 6) under submontaneous tracts of Punjab, India. Here, mulching reported to decrease the both runoff and soil loss. Further, Sidhu et al, 2010 also reported higher moisture regimes under zero tilled happy seeder plots where rice residues fully retained at the site as they act as mulch.

5. Zero tillage and the weed pressure

Divergent tillage systems affected weed pressure significantly in their own way. The reported number of weeds ha^{-1} was significantly higher in wheat-rice cropping sequence in plots under ZT than the plots under CT (Bhatt, 2015). Further, the weed biomass was also reported to be significantly higher in ZT plots (0.39 t ha^{-1}) than in CT plots (0.27 t ha^{-1}) (Bhatt, 2015). The ZT had been reported to increase weed density (Singh et al. 2015a; Singh et al. 2015b; Singh et al. 2014; Kumar et al., 2014) and increased the weed dry biomass (Singh et al., 2015a; Bhatt, 2015). Changes in tillage system, however, influences the vertical distribution of weed seeds in the soil profile (Singh et al. 2015b), and this may affect the relative abundance of weed pressure in the field. Under ZT, a large proportion of the weed seed placed on or close to the soil surface after sowing operations (Singh et al. 2015a; Bhatt, 2015), which received ample amount of moisture as well nutrients for their better germination. Thus, significantly higher weeds both in number and weight reported under the ZT plots while under CT plots, the weed seeds are deeply buried into the soil depending on the tillage equipment used and deeply buried these weed seeds may not be able to germinate because of inadequate supply of both moisture and nutrients (Bhatt, 2015).

Differential tillage systems placed the weed seeds at varying soil depths, where they may or may not able to receive the light, moisture and nutrients in ample amounts to germinate (Singh et al. 2015b). All these micro-environmental attributes have the potential to influence the behaviour of weed seed germination under differently tilled plots. Further, ZT plots reported to show lesser efficacy of the herbicides for the control of the weed in comparison to that of the CT plots and finally resulted in lower grain yields in former plots (Singh et al. 2015b).

6. Zero tillage and the environment

6.1 Atmosphere

Paddy-wheat rotation changes the soil C and N cycles and make the chemical specifications and biological effectiveness of nutrients varied with seasons, soil biomass and make more complicated soil physical changes (Fig. 7). Tillage practices in general breakdown the soil aggregates and oxidizes the once hidden organic matter into the atmosphere which on the long run deteriorates the soil quality. Tillage impact on the atmosphere occurs as radioactive gases emitted from the earth surface to the atmosphere (Lal et al., 2007).

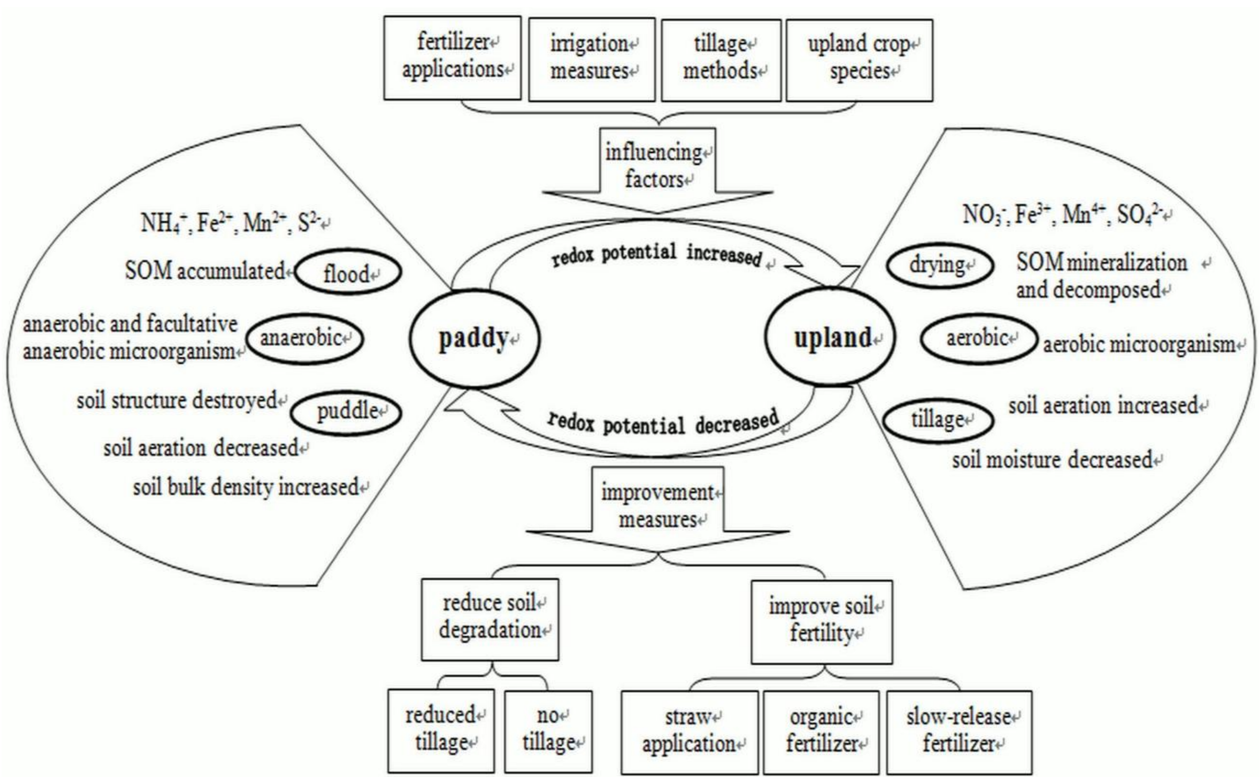

Fig. 7 Characteristics of Paddy-upland rotation and its improvement measures: Soil organic matter (used with permission Zhou et al, 2014).

About one-third of the global greenhouse gas emission is attributed to changes in tillage scenarios (Gattinger et al., 2014). Direct emissions from agriculture contributed 10-12% of global greenhouse gas emissions in 2010 (Tubiello et al. 2013). Further, UNEP (2013) emission gap report identified agriculture as the first of the four sectors that are contributing and have proven to be efficient in reducing greenhouse gas emissions. This report stressed onto the adoption of the zero-tillage practice to mitigate the global warming adverse effects.

Shifting from CT to ZT had been reported to yield a carbon sequestration rate of 367-3667 kg CO_2 ha^{-1} $year^{-1}$ (Tebrügge and Epperlein, 2011) as oxidation of CO_2 into the atmosphere has been checked to the marked extent. Further, conservation tillage practices decreased the exposure of un-mineralized organic substances to the microbial processes, thus reducing soil organic matter decomposition rate and CO_2 emission rates into the atmosphere (Gambolati et al., 2005). Other greenhouse gases viz. nitrous oxide (N_2O) and methane (CH_4) have been reported to be differently emitted by the different tillage regimes (Parkin and Kasper, 2006; Steinbach and Alvarez, 2006). According to Bellarby et al. (2008) approximately 38% emissions could be attributed to N_2O from soils while CH_4 is considered as the most potential greenhouse gas after carbon dioxide (IPCC, 2001). CT plots produced significantly higher N_2O emissions than ZT plots (Kessavalou et al. 1998). The higher aeration in CT plots increases oxygen availability, possibly resulting in increased aerobic turnover in the soil, oxidation of the soil organic matter and thus might have increased the emission of green house gases (Skiba et al., 2002). Thus, ZT option seems to be the more promising option in mitigating the adverse effects of the global warming by reducing the emission of the green house gases into the atmosphere.

6.2 Soil environment

ZT improved the soil physical, chemical and biological properties but it might have some adverse consequences viz. increased bulk density. Conservation tillage viz. minimum tillage significantly reduced soil loss and runoff than that of the conventionally tilled plots because of retained mulch loads (Bhatt and Khera, 2006). Under-ground water pollution chances are very small under ZT because of dramatic reduction in runoff. Further, under zero tilled plots, herbicides are very quickly broken down by soil organisms into harmless compounds (Duiker and Myers, 2005). When such agrochemicals are used in intensively ploughed soil they move more freely beyond the vadose zone compared to how it would be in the zero tilled plots. ZT in United States of America resulted in reduction of cropland erosion from 3.1 billion tonnes of soil to 1.9 billion tonnes between 1982 and 1997 (Claassen, 2012). Bhatt and Khera (2006) in Kandi Punjab, India observed 5 and 40% higher that runoff and soil loss under CT compared with minimum tillage. Intensive tillage significantly increased the erosion losses as it increased the susceptibility of the soil towards erosion. Intense soil erosion under conventionally tilled plots leads to removal of fertile soil (Alvarez et al. 1995), loss of nutrients (Bernardos et al. 2001) and finally loss of soil organic carbon (Hevia et al., 2003; Quiroga et al., 1996a) which decreases the soil quality and environment (Sagpya, 2008). However, CT loosens the soil; it buries the crop residues, weeds in the ground and exposes the soil to high-intensity rainfall and high wind speeds that lead to severe erosion (Lal et al., 2007). Conservation tillage practices, such as zero and minimum tillage are viable answer to the uplift the soil environment as it includes the full residue onto the plots (Miura et al., 2008; Bhatt and Khera, 2006h). Therefore, conservation tillage approach is a must for practising sustainable and climate smart agriculture by covering the bare soils, minimizing the erosion losses more particularly in the sub-mountainous tracts of the region which further improves the soil environment.

7. Conclusion

ZT technology required a set period of time for having their significant effect on different soil properties and environment. However, CT and ZT + mulching both have their own consequences. Thus, an effective integrated approach must be developed and tested at the farmer's level so as to reap the beneficial aspects of both tillage options. In this regards, minimum tillage serves as a bridge between the two tillage options which best serve the purpose. Further, it moderately improved the soil physico-chemical and biological properties along with mitigating adverse effect of the global warming and thus a step towards the sustainable agriculture.

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